Soft robotics

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Abstract

Soft robotics is a part of relatively new branch of bio-inspired robotics. As the name suggest, bio-inspired robotics takes inspiration from nature and uses structures and mechanisms found in bodies of animals. We can see that animals evolved to be able to survive in very unstructured and random world and are able to do wide range of different tasks. Today robots are mainly used in highly structured environments of completing halls and factories and cannot work in the real world. Soft robots are made of soft materials or act softly to achieve higher dexterity, usability in inaccessible places, and provide safety for human users. In this paper we give overview of current state of the field, materials and techniques used, and also some examples of concrete soft robots.

1. Introduction

Robotics is an important complement to the fields of cognitive science and artificial intelligence. There is a whole field of cognitive robotics that is concerned with giving robots intelligent behavior. Paradigm of embodied cognition says that cognition is tightly connected with the body of an agent and directly depends on it (Pfeifer & Bongard, 2007). Furthermore any artificial intelligence is of much greater use when embodied in physical body, and only with proper body an agent can do complex tasks.

Soft robotics was inspired by animals like worms, starfish or snails, or animal body parts like elephant trunk, octopus arm or mammalian tongue (Trivedi, Rahn, Kier, & Walker, 2008). Soft robots are characterized by being compliant thanks to elastic and soft materials like rubber or electroactive polymers used in their bodies. This softness brings some advantages and disadvantages compared to hard robotics. Soft robots offer higher dexterity, larger variability of movements, better usability in otherwise inaccessible places and higher safety. On the other hand, soft robots are harder to control because of virtually infinite number of degrees of freedom (DoFs) their bodies have. Control system of a robot also has to predict how the robot's body will behave under forces from loads and environment. To do so, physical modeling of the actuator has to be done, which is computationally demanding at least.

It is also possible to achieve soft like behavior in robots with hard body parts, but with many DoFs. For example there are robots that mimic snakes (Wright et al., 2007) or elephant trunk (Hannan & Walker, 2001) that are continuously deformable and may behave in compliant manner.

There is also another sense of term soft robotics (Albu-Schäffer et al., 2008), that refers to compliant hard robots. These robots can grasp and touch softly and are compliant to external forces. This compliance can be achieved by sensing and controlling torque in joints of a robot or by placing an elastic element into joints, creating compliance (or stiffness) mechanically in the hardware.

2. Soft robots

There are various ways to create soft or soft-like robot. In this part we are going to describe different approaches with their advantages and disadvantages.

2.1. Robots made of soft materials

There are various materials used to build soft robots. Electroactive polymers (EAP) are often used as artificial muscles (Bar-Cohen, 2000). Whole robots are usually made of multiple of these muscle-like actuators. EAPs are a branch of polymers that can contract and bend under applied voltage. They have lot of features that suit them for soft robotics. They can be made in any shape, are elastic, low weight and have large actuation strain (Trivedi, Rahn, Kier, & Walker, 2008). Also very useful is an ability of EAPs to sense how much stretched they are (Jung, Kim, & Choi, 2008). This is important when calculating (or 'sensing') the shape or the state of a robot's body. Examples of robots using EAPs are the robot mimicking earthworm (Jung, Koo, Lee, & Choi, 2007) or the starfish gel robot (Otake, Kagami, Inaba, & Inoue, 2002).

Other kind of soft actuators are the pneumatic artificial muscles (PAMs) (Trivedi et al., 2008). These are basically soft tubes with inflexible fiber mesh reinforcement in the wall of the tube or on its surface. When air is pumped in, the tube expands in its diameter and shrinks in longitudinal axis because the fiber cannot stretch. There is also an extensor PAM actuator in which the mesh is placed differently, so the tube extends only in longitudinal axis when pressurized. The second type was used for example to build octopus-like arm (Figure 1.) OctArm VI (Neppalli et al., 2007).

As mentioned above, controlling soft robots is rather hard. First part of the problem is to determine the actual position and shape of a robot. In case of hard robots it is quite easy to determine its shape, as we know where the DoFs (joints) are. We only need to know the angle of each joint and then calculate the position. Soft robots have infinite number of DoFs, however, there is always a finite number of sensors and actuators (muscles) in their bodies. Therefore it is impossible to have information about the state of each of the DoFs. Possible solution is determining the position of robot's body parts from outside, using visual information, when the robot would have camera to see the actual situation. Next part of the problem is determining what actions the robot should do to get in the desired positon. To determine the shape of a robot from internal and external forces, multiple physical models have to be employed, namely models for solid and fluid mechanics, kinematics, electro-mechanics, thermodynamics and chemical kinetics (Singh & Krishna, 2014). Simulating behavior of a continuum is, however, complicated problem demanding a lot of computational power. Sensing, control and path planning are main problems of today's soft robotics.

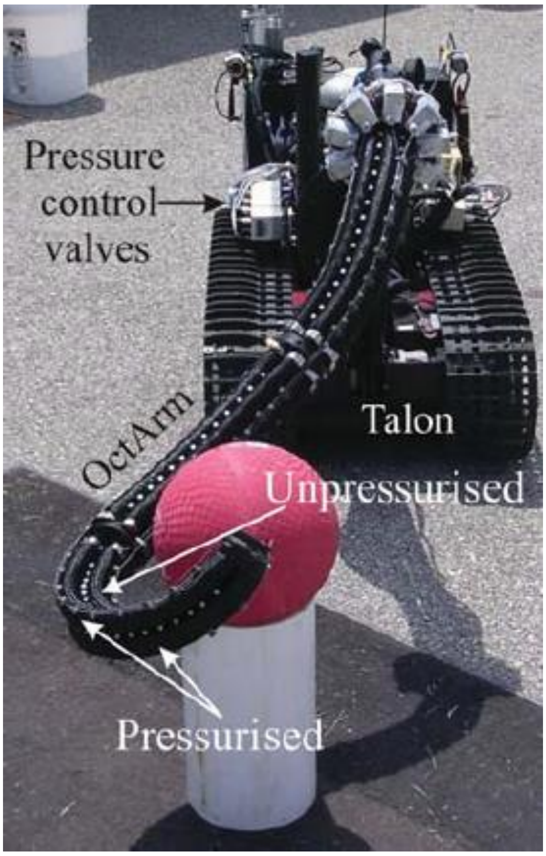

Figure 1.OctArm VI mounted on a mobile base (Trivedi et al., 2008).

2.2. Hyper-redundant hard robots with soft-like properties

A hyper-redundant robot has much more DoFs than theoretically needed for it to be able to reach any point of its surroundings. The large amount DoFs is where soft-like behavior comes from. With many DoFs a robot can bend as if it was made from soft continuum and with muscle-like actuators it may also be compliant. Examples are the aforementioned snake-like and trunk-like robots (Figure 2.) or the octopus robot (Laschi, Mazzolai, Mattoli, Cianchetti, & Dario, 2009). Artificial muscles are often used to actuate these robots.

Shape memory alloy (SMA) is an alloy, that when deformed, can return to its original shape if heated up to a certain temperature. It is an example of hard material that has an infinite number of DoFs. Despite being hard it can be used as muscle-like actuator. Example of a robot using SMA is the robot mimicking earth worm with peristaltic propulsion (Seok et al., 2013).

Figure 2. Hyper-redundant trunk-like robot (Trivedi et al., 2008).

Controlling these robots is also hard for similar reasons as in case of robots made entirely of soft materials. Coordination is used to decrease the number of DoFs. That means that certain muscles are activated together or in defined sequences to create meaningful movements (Trivedi et al., 2008). There are also attempts to control soft robots by artificial neural networks (ANNs). In their study Nakajima, Li, Kuppuswamy, and Pfeifer (2011) used ANNs to control simulated octopus arm. Several simplifications were made here, for instance only the angle between the arm and the base was controlled and propagation of this movement through the arm was used to reach a given point.

2.3 Hard robots with soft properties

Classical hard robots may be soft in terms of soft touch and interaction. For example there are many robots made by DLR (Deutsches Zentrum für Luft- und Raumfahrt e.V. - German Aerospace Center) (Albu-Schäffer et al., 2008). One way to get this kind of softness is software control, where the appropriate torque or force is calculated and then applied. The robot in this case measures the actual torque by sensors in joints for feedback, so it knows what force it is applying. This technique is called torque feedback control (Albu-Schäffer et al., 2008). Using it, we can get a robot that, for example, while doing a task, can be physically moved by a human user. The robot does not have to do certain task exactly the same way every time. When moved by a human it can adjust its actions so it can do the task from a new position.

Another way to achieve this kind of softness is to implement elastic element into the joints of a robot. Such element holds a joint in a certain position and force is needed to move it from the position. Motion of a joint is achieved by tensioning the elastic element in the joint. This is a concept of variable stiffness actuation (Albu-Schäffer et al., 2008). Elastic element may serve for storing energy or for damping impacts on the robot. In this way the robot can be inherently flexible even in case of actuator malfunction.

3. Challenges and future prospects

New faster, stronger and more reliable actuators and flexible and precise sensors are still needed for soft robots to become practical. But having materials with good properties isn't enough. There would still be a lot of questions about controlling and path planning for soft robots. Nowadays computers and models are not yet able to simulate behavior of soft body parts for real time control. Good physical models are essential for development of this field. Despite all the complications, there is great potential in use of soft robotics for example in medicine (surgery, prosthetics) or normal everyday assistance to humans.

4. Conclusion

There exist various approaches to soft robotics. The most natural one is usage of soft materials (EAPs, PAMs) to create robot's skeleton and artificial muscles. This way the robot is inherently soft and compliant. Another approach to achieve soft properties in a robot is to make it from hard parts but hyper-redundant (SMA) i.e. with much more DoFs than needed for robot to be able to reach any part of its nearby space. Combined with usage of artificial muscles it can be almost as soft and compliant as robots made purely of soft materials. Last mentioned approach is to make a classical hard robot soft (with soft touch) by controlling torque in its joints with designated software (torque feedback control) or by placing elastic element in the joints of the robot, making it compliant (variable stiffness actuation). Despite its achievements, soft robotics is still in early stages of development and there are many problems to be solved. Anyway, it is clear that soft robotics has much to offer and I think we are yet to discover all of its real possibilities.

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